APPENDIX C
CHARACTERISTICS OF FLARES

APPENDIX C CHARACTERISTICS AND ANALYSIS OF FLARES

1.0 INTRODUCTION

The Proposed Action would employ M-206 and MJU-7 A/B self-protection flares in additional airspace over parts of Georgia and South Carolina. Self-protection flares are magnesium pellets that, when ignited, burn for a short period of time (i.e., 3.5 to 5 seconds) at 2,000 degrees Fahrenheit (°F). The burn temperature is hotter than the exhaust of an aircraft, and therefore attracts and decoys heat-seeking weapons targeted on the aircraft. Flares are used in pilot training to develop the near instinctive reactions to a threat that are critical to combat survival. This appendix describes flare composition, ejection, risks and associated regulations.

2.0 FLARE COMPOSITION

Self-protection flares are primarily mixtures of magnesium and Teflon (polytetrafluoroethylene) molded into rectangular shapes (Air Force 1997). Longitudinal grooves provide space for materials that aid in ignition such as:

- First fire materials: potassium perchlorate, boron powder, magnesium powder, barium chromate, Viton A, or Fluorel binder.
- Immediate fire materials: magnesium powder, Teflon, Viton A, or Fluorel
- Dip coat: magnesium powder, Teflon, Viton A or Fluorel

Typically, flares are wrapped with an aluminum-filament-reinforced tape (wrapping) and inserted into an aluminum (0.03 inches thick) case that is closed with a felt spacer and a small plastic end cap (Air Force 1997). The top of the case has a pyrotechnic impulse cartridge that is activated electrically to produce hot gases that push a piston, the flare material, and the end cap out of the aircraft into the airstream. Table 1 provides a description of M-206 and MJU-7 A/B flare components. Typical flare composition and debris are summarized in Table 2. Figure 1 is an illustration of an M-206 flare, Figure 2 an illustration of an MJU-7 A/B flare.

Table 1. Description of M-206 and MJU-7 A/B Flares

Attribute	*M-206*	*MJU-7 A/B*
Aircraft	F-16, A-10, AC-130, C-17	F-16, AC-130
Mode	Parasitic	Semi-Parasitic
Configuration	Rectangle	Rectangle
Size	1 x 1 x 8 inches (8 cubic inches)	1 x 2 x 8 inches (16 cubic inches)
Impulse Cartridge	M-796	BBU-36/B; MJU-7 (T-1)/B Simulator uses M-796
Safe and Initiation Device	None	Slider Assembly
Weight (nominal)	6.8 oz	13 oz (T-1 type: 4.8 oz)
Comments	Simulator version (T-1) uses potassium chlorate, powdered sugar, and yellow dye smoke charge	Simulator version (T-1) uses potassium chlorate, powdered sugar, and yellow dye smoke charge

Table 2. Typical Composition of M-206 and MJU-7 A/B Self-Protection Flares

Part	*Components*
Combustible	
Flare Pellet	Polytetrafluoroethylene (Teflon) ($-[C_2F_4]_n$ – n=20,000 units) Magnesium (Mg) Fluoroelastomer (Viton, Fluorel, Hytemp)
First Fire Mixture	Boron (B) Magnesium (Mg) Potassium perchlorate ($KClO_4$) Barium chromate ($BaCrO_4$) Fluoroelastomer
Immediate Fire/ Dip Coat	Polytetrafluoroethylene (Teflon) ($-[C_2F_4]_n$ – n=20,000 units) Magnesium (Mg) Fluoroelastomer
Assemblage (Residual Components)	
Aluminum Wrap	Mylar or filament tape bonded to aluminum tape
End Cap	Plastic (nylon)
Felt Spacers	Felt pads (0.25 inches by cross section of flare)
Safe & Initiation (S&I) Device (MJU-7 A/B only)	Plastic (nylon, tefzel, zytel)
Piston	Plastic (nylon, tefzel, zytel)

Source: Air Force 1997

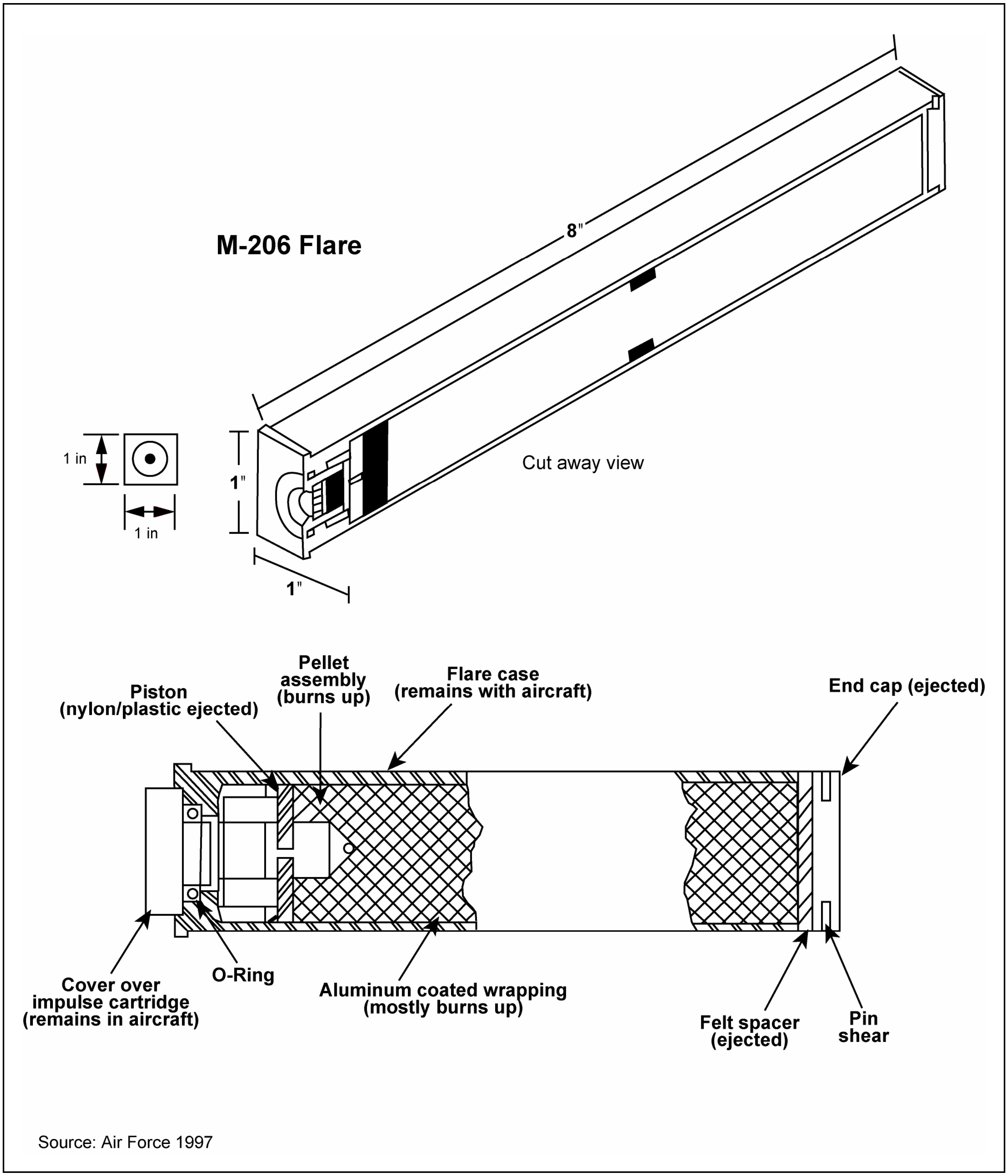

Figure 1. M-206 Flare

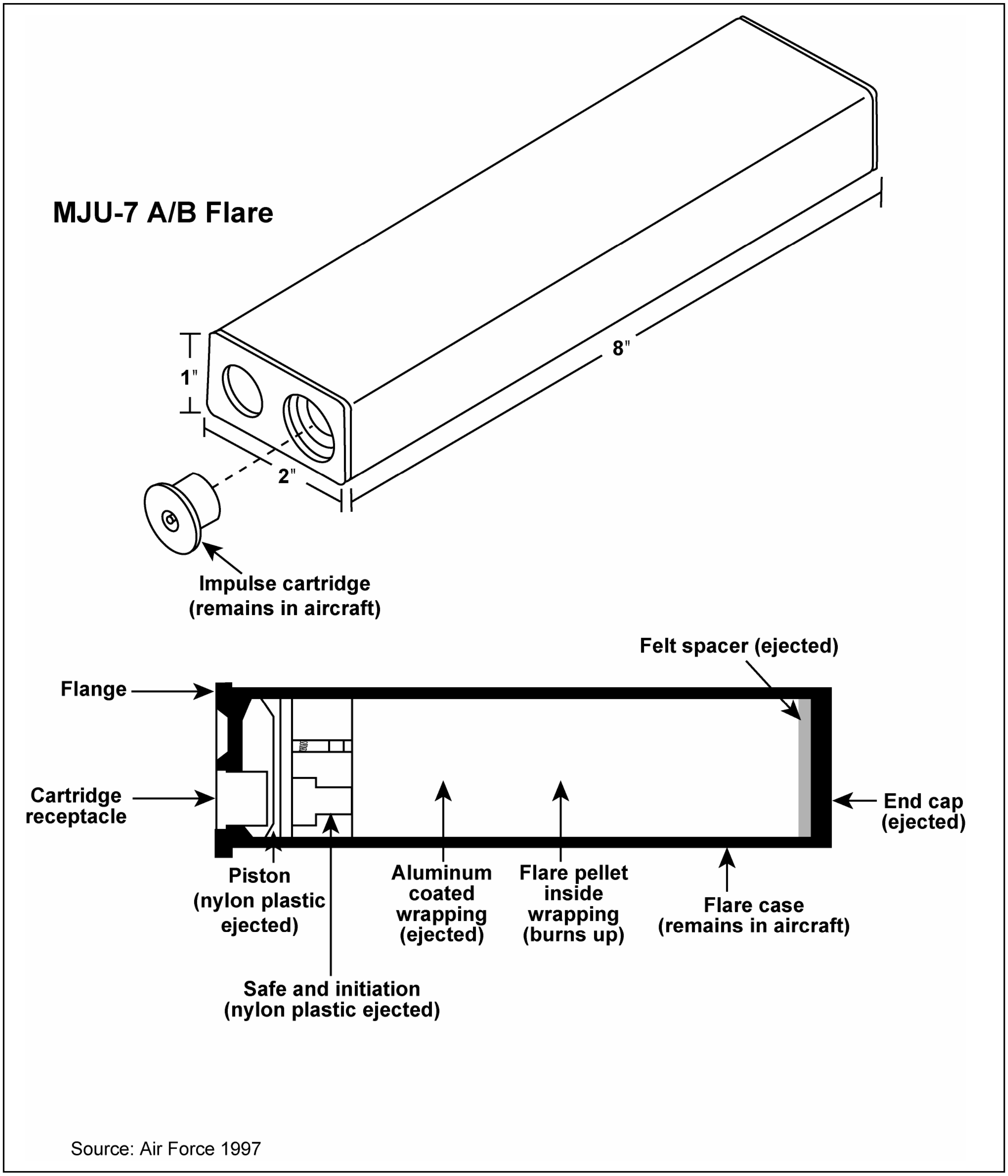

Figure 2. MJU-7 A/B Flare

3.0 FLARE EJECTION

M-206 is a parasitic-type flare that uses an M-796 impulse cartridge (Air Force 1997). It is ignited in the aluminum case before it leaves the aircraft. Holes in the piston permit ignitor gases to contact the first fire mixture on top of the flare pellet.

The MJU-7 A/B is a semi-parasitic type flare that uses a BBU-36/B impulse cartridge. In this flare, a slider assembly incorporates an initiation pellet (640 mg of magnesium, Teflon, and Viton A or Fluorel binder). This pellet is ignited by the impulse cartridge, and hot gases reach the flare as the slider exits the case, exposing a fire passage from the initiation pellet to the first fire mixture on top of the flare pellet. Table 3 describes the components of M-796 and BBU-36/B impulse charges.

Flares are tested to ensure they meet performance requirements in terms of ejection, ignition, and effective radiant intensity. If the number of failures exceeds the upper control quality assurance acceptance level (approximately 99 percent must be judged reliable for ejection, ignition, and intensity), the flares are returned to the manufacturer. Flare failure would occur if the flare failed to eject, did not burn properly, or failed to ignite upon ejection. For training use within the airspace, a dud flare would be one that successfully ejected but failed to ignite. That probability is projected to be 0.01 percent based upon dud flares located during military range cleanup.

4.0 RISKS ASSOCIATED WITH FLARE USE

Risks associated with the use of flares fall within two main categories: the risk of fire from a flare and the risk of being struck by a residual flare component.

4.1 Fire Risk

Fire risk associated with flares stems from an unlikely, but possible scenario that results in the flare reaching the ground or vegetation while still burning. The altitude from which flares are dropped is strictly regulated by the airspace manager, and is based on a number of factors including flare burn-out rate. The flare burn-out rate is shown in Table 4. Defensive flares typically burn out in 3.5 to 5 seconds, during which time the flare will have fallen between 200 and 400 feet. Specific defensive flare burn-out rates are classified. Table 4 is based on conditions that assume zero aerodynamic drag and a constant acceleration rate of 32.2 feet per second per second.

$D = (V_o * T) + (0.5 * (A * T^2))$

Where:

D = Distance
Vo = Initial Velocity = 0
T = Time (in Seconds)
A = Acceleration

Table 3. Components of M-796 and BBU-36/B Impulse Charges

Component	*M-796*	*BBU-36/B*
Overall Size Overall Volume Total Explosive Volume	0.449 x 0.530 inches 0.104 cubic inches 0.033 cubic inches	0.740 x 0.550 inches 0.236 cubic inches 0.081 cubic inches
Bridgewire	Trophet A 0.0025 inches (diameter)	Trophet A
Closure Disk	Scribed disc, washer	Scribed disc, washer
Initiation Charge		
Volume	0.011 cubic inches	0.01 cubic inches
Weight	100 mg	100 mg
Compaction	5,500 psi	6,200 psi
Composition	20% boron 80% calcium chromate	42.5% boron 52.5 % potassium perchlorate 5.0% Viton A
Booster Charge		
Volume	0.011 cubic inches	0.01 cubic inches
Weight	70 mg	150 mg
Compaction	5,500 psi	5,100 psi
Composition	18% boron 82% potassium nitrate	20% boron 80% potassium nitrate
Main Charge		
Volume	0.011 cubic inches	0.061 cubic inches
Weight	185 mg	655 mg
Compaction	Loose fill	Loose fill
Composition	Hercules HPC-1 (~40% nitrocellulose)	Hercules #2400 smokeless powder (50-77% nitrocellulose, 15-43% nitroglycerine)

Source: Air Force 1997

Table 4. Flare Burn-out Rates

Time (in Sec)	*Acceleration*	*Distance (in feet)*
0.5	32.2	4.025
1.0	32.2	16.100
1.5	32.2	36.225
2.0	32.2	64.400
2.5	32.2	100.625
3.0	32.2	144.900
3.5	32.2	197.225
4.0	32.2	257.600
4.5	32.2	326.025
5.0	32.2	402.500
5.5	32.2	487.025
6.0	32.2	579.600
6.5	32.2	680.225
7.0	32.2	788.900
7.5	32.2	905.625
8.0	32.2	1030.400
8.5	32.2	1163.225
9.0	32.2	1304.100
9.5	32.2	1453.025
10.0	32.2	1610.000

Note: Initial velocity is assumed to be zero.

4.2 Flare Strike Risk

Residual flare materials are those that are not completely consumed during ignition and fall to the ground, creating the risk of striking a person or property. For the M-206 flare, residual materials consist of a plastic end cap, a piston, one or two felt spacers, and a piece of aluminum coated wrapper (Table 5). Residual material from the MJU-7 A/B consists of an end cap, an initiation assembly (safe and initiation device), a piston, one or two felt spacers, and an aluminum coated wrapper (Table 5). For both flare types, the wrapper may be partially consumed during ignition, so the wrapping residual material could range in size from the smallest size, 1 inch by 1 inch, to the largest size, 3 inches by 13 inches. The size of the residual wrapping material would depend upon the amount of combustion that occurred as the flare was deployed.

Table 5. Residual Material from M-206 and MJU-7 A/B Flares

Component	*Weight*
M-206	
Plastic end cap	0.0061 pounds
Piston and cushion assembly	0.0043 pounds
Felt spacer	0.0013 pounds
Wrapper (2 inches x 13 inches)	0.0215 pounds
MJU-7 A/B	
End cap	0.0072 pounds
Safe & Initiation (S&I) device	0.0453 pounds
Piston	0.0072 pounds
Felt spacer	0.0011 pounds
Wrapper (3 inches x 13 inches)	0.0322 pounds

After ignition, as described in section 3.0, residual components of the M-206 flare and most residual components of the MJU-7 A/B flare have high surface to mass ratios and are not judged capable of damage or injury when they impact the surface. One component of the MJU-7 A/B flare, referred to as the Safe and Initiation (S&I) device, has a weight of approximately 0.725 ounces (0.0453 pounds). It is sized and shaped such that it is capable of achieving a terminal velocity that could cause injury if it struck a person. This section calculates the likelihoods of such an S&I device striking a person, a private structure, or a vehicle under either the Gamecock MOAs or the Bulldog MOAs.

4.2.1 TECHNICAL APPROACH

Shaw AFB aircraft training flights are distributed randomly and uniformly within the Bulldog and Gamecock MOAs. Avoidance areas that are designated for low altitude flight need not be avoided for higher altitude flight. Flare component release altitudes and angles of release are sufficiently random that ground impact locations of flare materials are also assumed to be uniformly distributed under the MOAs.

For any particular residual component of a released flare, the conditional probability that it strikes a particular object is equal to the ratio of the object area to the total area of the MOA. For multiple objects (i.e. people, structures, vehicles), the probability of striking any one object is the ratio of the sum of object areas to the MOA. The frequency of a residual component striking one of many objects is the frequency of releasing residual components times the conditional probability of striking one of the many objects per given release.

In equation form, this relationship is:

$$Strike\ frequency = component\ drop\ frequency\ in\ MOA \times \frac{area\ of\ object \times number\ of\ objects\ in\ MOA}{MOA(area)}$$

The potential consequences of a residual component with high velocity and momentum striking particular objects are postulated as follows:

- Striking the head of an unprotected individual: possible concussion
- Striking the body of an unprotected individual: possible injury
- Striking a private structure: possible damage
- Striking a private vehicle: possible damage (potential injury if vehicle moving)

The frequencies of each of these consequences are estimated for the two MOAs.

4.2.2 RISK/FREQUENCY ESTIMATION

The frequency of each of the strike consequences is computed as the product of the frequency of releasing residual components with high momentum and the conditional probability of striking people, structures, or vehicles. These estimates are developed in the following paragraphs.

4.2.2.1 FREQUENCY AND MOMENTUM OF RELEASED RESIDUAL MJU-7 A/B COMPONENTS

Current projections indicate approximately 6,500 MJU-7 A/B flares per year deployed within the Gamecock MOAs and 8,600 MJU-7 A/B flares per year deployed within the Bulldog MOAs.

The effect of the impact of a residual MJU-7 A/B component from Table 6 is judged by computing the component's terminal velocity and momentum.

Terminal velocity (V_T) is calculated by the equation:

$$V_T = \left[\frac{2}{\rho}\left(\frac{W}{A \times C_d}\right)\right]^{0.5} = 29 \times \left(\frac{W}{A}\right)^{0.5}$$

Where: V_T = Terminal Velocity (in Feet/Second)
ρ = Nominal Air Density (2.378×10^{-3} lbs-sec^2/ft^4)
W = Weight (in Pounds)
A = Surface Area Facing the Air stream (in ft^2)
C_d = Drag Coefficient = 1.0

Drag coefficients are approximately 1.0 over a wide range of velocities and Reynolds numbers (Re) for irregular objects (e.g. non-spherical). Using this drag coefficient, the computed terminal velocities (Table 7) produce Re values within this range ($Re < 2 \times 10^5$), which justifies the use of the drag coefficient.

The weights and geometries of major flare components are approximately as listed in Table 6.

Table 6. MJU-7 A/B Flare Major Component Properties

Component	*Geometry*	*Dimensions (inches)*	*Weight (Pounds)*
S&I device	Rectangular solid	2 × 0.825 × 0.5	0.0453
Piston	Rectangular open	2 × 0.825 × 0.5	0.0072
End Caps	Rectangular plate	1 × 2 × 0.125	0.0072

Terminal velocity momentums of these components are computed based on maximum (two square inches) and minimum (one square inch) areas and are listed in Table 7. Actual values would be between these extremes. The momentum values are the product of mass (in slugs) and velocity. A slug is defined as the mass that, when acted upon by a 1-pound force, is given an acceleration of 1.0 ft/sec^2.

Table 7. MJU-7 A/B Flare Component Hazard Assessment

	MAXIMUM SURFACE AREA			MINIMUM SURFACE AREA		
Component	*Area (in^2)*	*Terminal Velocity (ft/sec)*	*Momentum (lb-sec)*	*Area (in^2)*	*Terminal Velocity (ft/sec)*	*Momentum (lb-sec)*
S&I device	1.65	58	0.08	0.413	115	0.16
Piston	1.65	23	0.005	0.413	46	0.01
End Caps	2.0	21	0.005	0.125	84	0.02

The focus of this analysis will be the S&I device. Other flare components are not calculated to achieve a momentum that could cause damage.

4.2.2.2 ESTIMATED AREAS OF PEOPLE, STRUCTURES, AND VEHICLES

People at risk of being struck by a dropped flare component are assumed to be standing outdoors under a MOA (people in structures or vehicles are assumed protected). The dimensions of an average person are assumed to be 5 foot 6 inches high by 2 feet wide by 1 foot deep (men 5 foot 10 inches; women 5 foot 4 inches; children varied). The S&I device is expected to strike ground objects at an angle of 80° or greater to the ground, assuming 80° to the ground allows for possible wind or other drift effects. With the flare component falling at 80° to the ground, a person's body (5.5 × 2 × 1 feet) projects an area of 3.9 ft^2 normal to the path of the dropped component.

The number of people within each MOA is estimated based on census data. Within the Gamecock MOA complex, overall population density is 55.3 persons/mi^2, and within the Bulldog MOA complex it is 39.8 persons/mi^2 (U.S. Bureau of the Census 2000). For this assessment, it is assumed that a person would be outdoors and unprotected 10 percent of the time (Tennessee Valley Authority 2003; Klepeis et al. 2001).

Structure and vehicle densities are estimated from 2000 census data. Based on Bureau of the Census data, average family size in the areas underlying both the Gamecock and Bulldog MOA complexes is 2.65 persons (U.S. Bureau of the Census 2000). This equates to approximately 21 and 15 families/mi^2 under the Gamecock and Bulldog MOA complexes, respectively. As a conservative estimate, it is assumed that each family could have or otherwise use the equivalent of two structures associated with their property and own two vehicles. Thus, it was assumed that there would be 42 and 30 structures/mi^2 and 42 and 30 vehicles/mi^2 on the Gamecock and Bulldog MOAs, respectively. The average area of each of the two structures on each property under a MOA is estimated to be 1500 ft^2 and the average area of each of the two vehicles per family is estimated to be 100 ft^2.

4.2.2.3 POTENTIAL PERSONNEL INJURIES

The frequencies of the identified consequence categories can be computed based on the methodology discussed in Section 4.2.1 and the data and assumptions discussed above. Flight maneuvers to deploy flares are assumed to be randomly distributed throughout the training airspace.

A personnel injury could occur if an S&I device struck an unprotected person. The frequency of striking a person is:

$$Injury\ frequency = comp\,drop\ freq \times \frac{body\,area \times pop.density \times Fract\,unprot \times MOA(area)}{MOA(area)}$$

For the Gamecock MOA:

$$Gamecock\,injury\ frequency = 6500/\,year \times 3.9\ ft^2/\,pers \times 55.3\,pers/\,mi^2 \times 0.1 \times 3.59 \times 10^{-8}\,mi^2/\,ft^2$$
$$= 0.005 \text{ injuries/year}$$

For the Bulldog MOA:

$$Bulldog\,injury\ frequency = 8600/\,year \times 3.9\ ft^2/\,pers \times 39.8\,pers/\,mi^2 \times 0.1 \times 3.59 \times 10^{-8}\,mi^2/\,ft^2$$
$$= 0.005 \text{ injuries/year}$$

The maximum momentum of the S&I device would vary between 0.08 and 0.16 pound-seconds depending upon orientation. In this momentum range, an injury is postulated that could be equivalent to a bruise from a large hailstone. Approximately 20 percent of any strikes could be to the head. A potentially more serious injury could be expected if the head were struck.

As a basis of comparison, laboratory experimentation in accident pathology indicates that there is a 90 percent probability that brain concussions would result from an impulse of 0.70 pound-seconds to the head, and less than a 1 percent probability from impulses less than 0.10 pound-seconds (Air Force 1997). The only MJU-7 A/B component with momentum values near 0.10 pound-seconds is the S&I device with a momentum between 0.08 and 0.16 pound-seconds. A strike of an S&I device to the head has approximately a 1 percent probability of causing a concussion.

4.2.2.4 STRUCTURE IMPACT

The expected annual number of S&I devices striking structures is calculated to be:

$$Sructure\ strike\ \ frequency = comp\ drop\ \ freq \times \frac{struct.area \times struct.density \times MOA(area)}{MOA(area)}$$

For the Gamecock MOA:

$$Gamecock\ strike\ \ frequency = 6500 / year \times 1500\ \ ft^2 / struct \times 42\ struct / mi^2 \times 3.59 \times 10^{-8}\ mi^2 / ft^2$$
= 15 impacted structures/year

For the Bulldog MOA:

$$Bulldog\ strike\ \ frequency = 8600 / year \times 1500\ \ ft^2 / pers \times 30\ struct / mi^2 \times 3.59 \times 10^{-8}\ mi^2 / ft^2$$
= 14 impacted structures/year

The maximum momentum of the S&I device would vary between 0.08 and 0.16 pound-seconds depending upon orientation. This would be comparable to a large hailsone and would not be expected to damage a structure.

4.2.2.5 VEHICLE IMPACT

The expected annual number of S&I devices striking a vehicle is calculated to be:

$$Vehicle\ strike\ \ frequency = comp\ drop\ \ freq \times \frac{veh.area \times veh.density \times MOA(area)}{MOA(area)}$$

For the Gamecock MOA:

$$Gamecock\ strike\ \ frequency = 6500 / year \times 100\ \ ft^2 / veh \times 42\ veh / mi^2 \times 3.59 \times 10^{-8}\ mi^2 / ft^2$$
= 1.0 impacted vehicles/year

For the Bulldog MOA:

$$Bulldog\ strike\ \ frequency = 8600 / year \times 100\ \ ft^2 / veh \times 30\ veh / mi^2 \times 3.59 \times 10^{-8}\ mi^2 / ft^2$$
= 0.9 impacted vehicles/year

The S&I device maximum momentum would vary between 0.08 and 0.16 pound-seconds depending upon orientation. A strike to a vehicle could cause a cosmetic dent similar to a hailstone impact. Although not numerically estimated, a strike to a moving vehicle could result in a vehicle accident.

4.3 Summary

The risk assessment described in this section was performed to estimate the likelihood of MJU-7 A/B flare components striking an unprotected person or property. The assessment assumed rates of usage of the MJU-7 A/B flares consistent with the estimated use of flares in Gamecock and Bulldog MOAs in 2004. The results of the assessment are summarized in Table 8.

Table 8. Likelihood of MJU-7 A/B Component Strike

Consequence Type	*Expected Value Bulldog MOA (events/year)*	*Expected Value Gamecock MOA (events/year)*
Personnel Injuries	0.005	0.005
Private Structures Struck	14	15
Private Vehicles Struck	0.9	1.0

The expected value or expected frequency presented in Table 8 is based upon the same mathematics that occur when a coin is flipped. The expected frequency of tails in 10 coin flips/year is 10 flips/year x 0.5 probability of tails per coin flip = 5 expected tails/year.

The conditional probability of one dropped flare component striking an object or a body is included in the Table 8 calculation. For example, under the Gamecock MOAs, this probability is 7.34 E-07. The product of this probability and the drop frequency, 6500/year, gives the expected value of 0.005 body strikes/year. All the expected strike values take into consideration the number of people, area under the airspace, and the number of MJU-7 A/B flares proposed to be used. The 0.005 number is the calculated potential to strike an unprotected person in each of the Bulldog and Gamecock MOAs. This is analogous to the estimated 14 private structures and slightly fewer than 1.0 (0.9) vehicle per year under the Bulldog MOAs. This calculated expected 9 vehicles struck in 10 years is relatively high compared with means that 5 persons in 1,000 years or 1 person in 200 years. Since the head represents approximately 20 percent of a person's exposed surface area, and approximately 1 percent of head impacts could result in a concussion, the expected frequency of a concussion under either the Bulldog or Gamecock MOAs is approximately 1 in 100,000 years.

These estimated expected values have been computed as nominal values; they are not statistically biased in either a conservative or non-conservative direction. These risk values are computed to support Air Force evaluations of the risks of using MJU-7 A/B flares in the Gamecock and Bulldog MOAs.

5.0 POLICIES AND REGULATIONS ADDRESSING FLARE USE

Air Force policy on flare use was established by the Airspace Subgroup of Headquarters (HQ) Air Force Flight Standards Agency (AFFSA) in 1993 (Memorandum from John R. Williams, 28 June 1993) (Air Force 1997). This policy permits flare drops over military-owned or controlled land and in Warning Areas. Chaff and flares use in the Gamecock and Bulldog Military Operations Areas (MOAs) was analyzed in the Shaw AFB Chaff and Flares EA (Air Force 2003). Flare drops are permitted in MOAs and Military Training Routes (MTRs) only when an environmental analysis has been completed. Minimum altitudes must be adhered to. Flare drops must also comply with established written range regulations and procedures.

AFI 11-214 prohibits using flare systems except in approved areas with intent to dispense, and sets certain conditions for employment of flares. Flares are authorized over government-owned and controlled property and over-water Warning Areas with no minimum altitude restrictions when there is no fire hazard. If a fire hazard exists, minimum altitudes will be maintained in accordance with the applicable directive or range order. An ACC supplement to AFI 11-214 (15 October 2003) prescribes a minimum flare employment altitude of 2,000 feet AGL over non-government owned or controlled property (Air Force 1997).

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